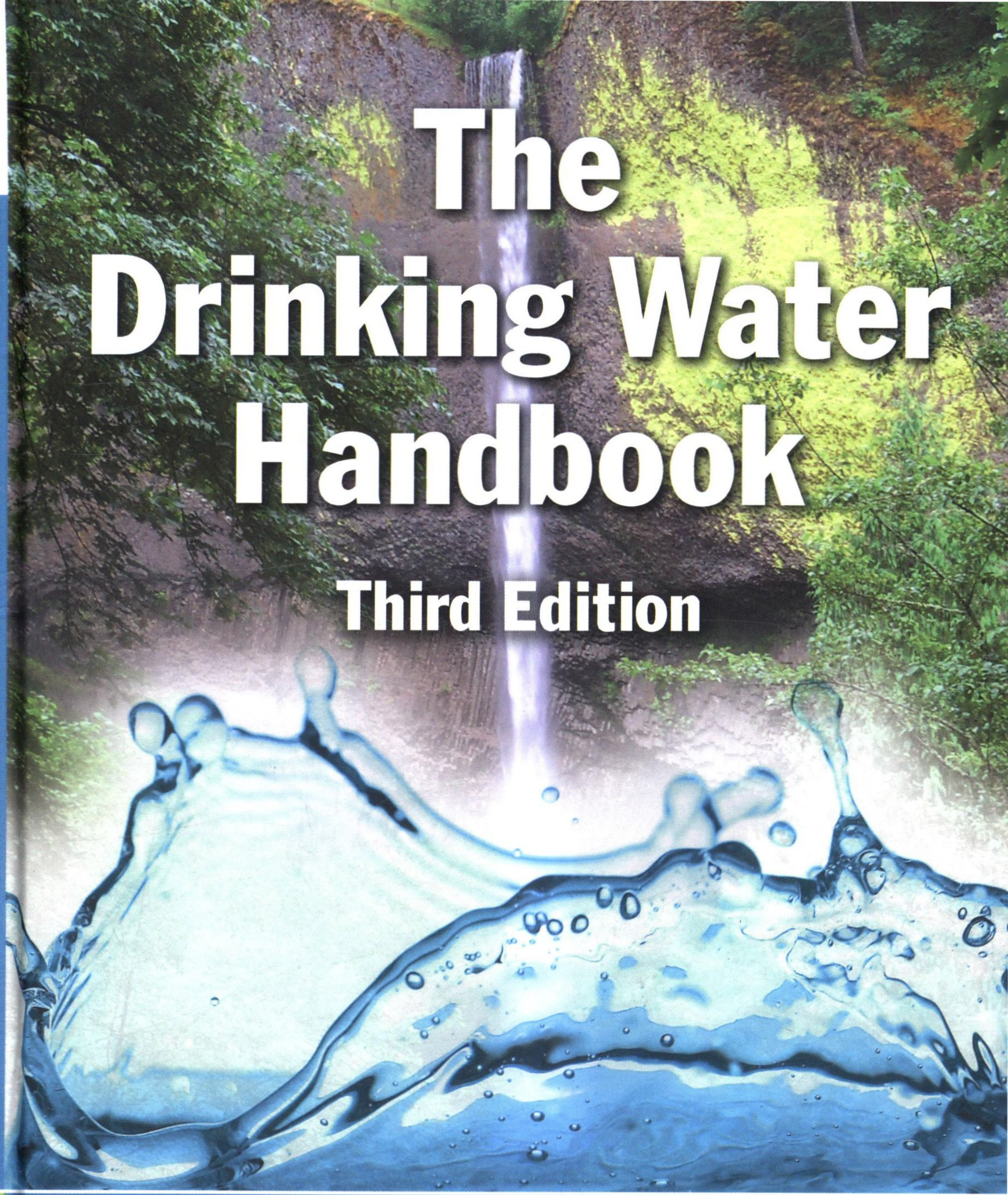

The Drinking Water Handbook

Third Edition

Frank R. Spellman

CRC Press
Taylor & Francis Group

WATER SCIENCE AND ENGINEERING

Third Edition

The Drinking Water Handbook

When you open the tap to fill your glass with drinking water, you expect the water to be of good quality. But is the water from your tap really safe? This third edition of an industry-wide bestseller, ***The Drinking Water Handbook,*** explains the many processes employed to make water safe to drink.

Engaging and accessible, the handbook covers important concepts and regulations and identifies current problems with water supplies. In addition to the traditional physical, chemical, and microbiological parameters that affect water quality, it discusses trihalomethanes, *Cryptosporidium,* viruses, carcinogens, pharmaceuticals, and other pollutants.

The book also addresses the challenges faced by practitioners striving to provide the best drinking water quality to the consumer. It outlines techniques and technologies for monitoring and water treatment, from preliminary screening to filtration and disinfection, as well as advanced processes for specialized water problems.

This new edition has been thoroughly revised and updated, and includes a comprehensive discussion of the Flint, Michigan lead contamination event, new coverage of contaminants in water, such as personal care products and pharmaceuticals (PCPP) and endocrine disruptors, and examines the security requirements for waterworks and ancillary processes. It examines the sources of drinking water, the purification process, through distribution to the tap, to the actual use and reuse of water. It also reflects the latest advancements in treatment technologies and reviews new laws and regulations related to drinking water.

This user-friendly handbook puts technical information about drinking water in the hands of the general public, sanitary and public works engineers, public health administrators, water treatment operators, and students. It takes a close look at what can be found in many tap water supplies and the measures taken to ensure the health and well-being of consumers.

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Prologue—Sick Water Revisited

The term *sick water* was coined by the United Nations in a 2010 press release addressing the need to recognize that it is time to arrest the global tide of sick water. The gist of the United Nation's report was that transforming waste from a major health and environmental hazard into a clean, safe, and economically attractive resource is emerging as a key challenge in the 21st century. Practitioners of environmental health certainly support the United Nation's view on this important topic.

When discussing sick water in the context of this text, however, it is necessary to go a few steps further than the United Nations did to describe the real essence and tragic implications of supposedly potable water that makes people or animals sick or worse. Water that is sick is actually filthy spent water or wastewater—a cocktail of fertilizer runoff and sewage disposal alongside animal, industrial, agricultural, and other wastes. In addition to these listed wastes of concern, other wastes are beginning to garner widespread attention. What are these other wastes? Any waste or product that we dispose of in our waters, that we flush down the toilet, pour down the sink or bathtub drain, or pour down the drain of a worksite deep sink. Consider the following example of pollutants we routinely discharge to our wastewater treatment plants or septic tanks—wastes we don't often consider as waste products but that in reality are.

Each morning a family of four, two adults and two teenagers, wakes up and prepares for the day that lies ahead. Fortunately, this family has three upstairs bathrooms to accommodate everyone's needs, and each day the family's natural wastes, soap suds, cosmetics, hair treatments, vitamins, sunscreen, fragrances, and prescribed medications end up down the various drains. In addition, the overnight deposits of cat and dog waste are routinely picked up and flushed down the toilet. Let's examine a short inventory of what this family of four has disposed of or has applied to themselves during their morning rituals:

- Toilet-flushed animal wastes
- Prescription and over-the-counter therapeutic drugs
- Veterinary drugs
- Fragrances
- Soap
- Shampoo, conditioner, other hair treatment products
- Body lotion, deodorant, body powder
- Cosmetics
- Sunscreen products
- Diagnostic agents
- Nutraceuticals (e.g., vitamins, medical foods, functional foods)

Even though these bioactive substances have been around for decades, today they are all (with the exception of animal wastes) grouped under the title of *pharmaceuticals and personal care products*, or PPCPs (see Figure 1).

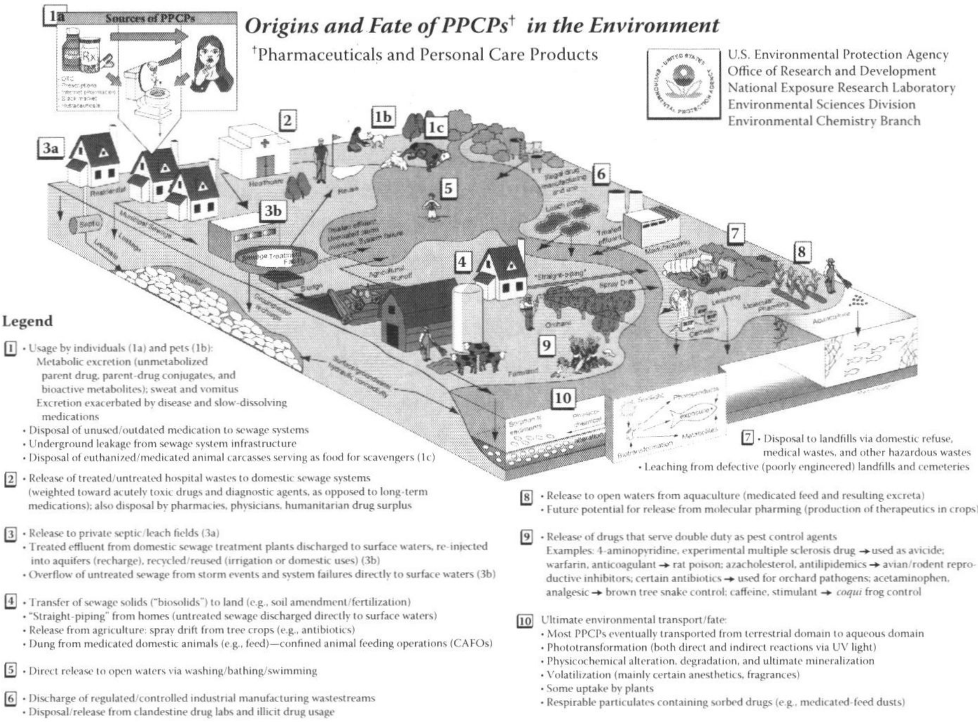


FIGURE 1 Origins and fate of PPCPs in the environment. (From USEPA, *Origins and Fate of PPCPs in the Environment*, U.S. Environmental Protection Agency, Washington, DC, 2006.)

Returning to our family of four, after having applied, used, or ingested the various substances mentioned earlier, they also add at least traces of these products (PPCPs) to the environment through excretion (the elimination of waste material from the body) and bathing, as well as through disposal of any unwanted medications to sewers and trash. How many of us have found old prescriptions in the family medicine cabinet and disposed of them with a single toilet flush? Many of these medications (e.g., antibiotics) are not normally found in the environment. Earlier we stated that wastewater is a cocktail of fertilizer runoff and sewage disposal with additions of animal, industrial, agricultural, and other wastes. When we add PPCPs to this cocktail we can state that we are simply adding mix to the mix.

This mixed-waste cocktail raises many questions: Does the disposal of antibiotics or other medications into the local wastewater treatment system cause problems for anyone or anything downstream? When we drink locally treated tap water are we also ingesting flushed-down-the-toilet or rinsed-down-the-drain antibiotics, other medications, illicit drugs, animal excretions, cosmetics, vitamins, personal or household cleaning products, sunscreen products, diagnostic agents, crankcase oil, grease, oil, fats, and veterinary drugs and hormones?

If the family of four were shown the list of pharmaceuticals and personal care products they routinely used and disposed of each morning, they might be surprised, impressed, or totally uninterested. Suppose, however, that after this family was shown the list of products they used and disposed of in the wastestream that left their home, they were asked if they would be willing to drink from that same wastestream. It is very likely that they would no longer be disinterested. In fact, they would probably be experiencing a queasy feeling in their stomachs that is commonly referred to as the "yuck factor."

The yuck factor raised by drinking human-created wastestreams is grossly overstated. The fact is we have been drinking from these wastestreams from time immemorial—beyond time or memory. Consider the mythical hero Hercules (arguably the world's first environmental engineer), who performed his fifth labor by cleaning up King Augeas' stables. Hercules, faced literally with a mountain of horse and cattle waste piled high in the stable area, had to devise some method to dispose of the waste. He diverted a couple of rivers to the stable interior, and they carried off all of the animal waste: Out of sight, out of mind. The waste followed the laws of gravity and flowed downstream, becoming someone else's problem. Hercules understood the principal point in pollution control technology, one that is pertinent to this very day: *Dilution is the solution to pollution.*

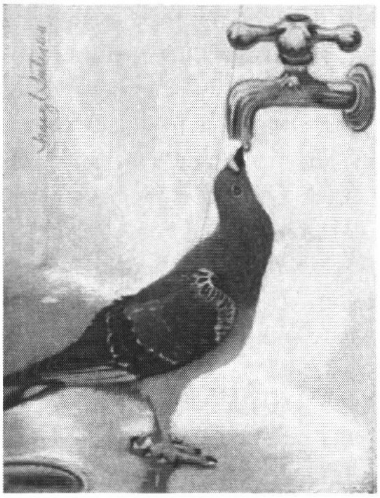
Apart from Hercules' reasonable approach to disposing of waste in his time, another factor to consider is *de facto* water recycling. When the family of four and others say they would never drink toilet water, they have no idea what they are saying. As pointed out in the third edition of my textbook, *The Science of Water*, the fact is we drink recycled wastewater every day via the *de facto* water cycle, which turns the yuck factor into an "awe" factor. Wastewater treatment plants throughout the industrialized world treat wastewater or used water and then discharge the treated water to major rivers or other local water bodies. Many of those region's rivers are sources of local drinking water supplies, and local groundwater supplies are routinely infiltrated with surface water inputs, which, again, are commonly supplied by treated wastewater (and sometimes infiltrated by raw sewage that is accidentally spilled). Nature takes care of the water pollution problem—to an extent; however, PPCPs may be the exception. The water cycle process results in some uncertainty regarding their fate, which is discussed in the text.

The jury is still out on the topic of PPCPs. We simply do not know what we do not know about the fate of PPCPs or their impact on the environment once they enter our wastewater treatment systems, the water cycle, and eventually our drinking water supply systems. We do know that some PPCPs are easily broken down and processed by the human body or degraded quickly in the environment, but the disposal of certain wastes can be problematic for quite some time.

Another issue related to contaminants in our water systems is one many of us never think about. Water is used by all living organisms, including wildlife and aquatic life. The fact is water pollution can severely harm marine, avian, and land animals. In addition to PPCPs, other contaminants found in our water bodies include the following:

- Raw sewage running into lakes, rivers or streams
- Industrial waste spills contaminating groundwater
- Radiation spills or nuclear accidents
- Illegal dumping of substances or items within bodies of water
- Biological contamination, such as bacterial growth
- Farm runoff into nearby bodies of water

It is also important to point out that drinking water sources and animal usage represent a double-edged sword. Animals have a right to drink from unpolluted and safe drinking water sources, but wildlife, farm animals, and other animals also contribute to drinking water pollution. This is why when in the woods or at campsites or other remote locates it is always wise to filter river, stream, or lake water with a 1-micron filter prior to drinking the water.



We all get thirsty.

The fly in this pollution solution ointment is today's modern PPCPs. Although Hercules was able to dispose of animal waste into a running water system where eventually the water's self-purification process cleaned the stream, he did not have to deal with today's personal pharmaceuticals and the hormones that are given to many types of livestock to enhance health and growth. Studies show that pharmaceuticals are present in our nation's water bodies, and research suggests that certain drugs may cause ecological harm. The USEPA and other research agencies are committed to investigating this topic and developing strategies to help protect the health of both the environment and the public. To date, scientists have found no hard evidence of adverse human health effects from PPCPs in the environment. Some might argue that these PPCPs represent only a small fraction (expressed in parts per trillion, 10^{-12}) of the total volume of water, that we are speaking of a proportion equivalent to 1/20 of a drop of water diluted into an Olympic-size swimming pool. One student in an environmental health class stated that he did not think the water should be called "sick water," as it was evident to him that water containing so many medications could not be sick. Instead, it might be termed "well water," with the potential to make anyone who drinks it well.

It is important to point out that the term *sick water* can be applied not only to PPCP-contaminated water but also to any filthy, dirty, contaminated, polluted, pathogen-filled drinking water sources. The fact is dirty or sick water means that, worldwide, more people now die from contaminated and polluted water than from all forms of violence, including wars.* The United Nations observed that dirty or sick water is a key factor in the rise of deoxygenated dead zones that have been emerging in seas and oceans across the globe.

* Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D., and Savelli, H., Eds., *Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment*, United Nations Environment Programme (UNEP), UN-HABITAT, GRID-Arendal, 2010.

Preface to Third Edition

The first and second editions of *The Drinking Water Handbook* were industrywide bestsellers hailed as masterly accounts written in an engaging, highly readable style. The third edition continues where the first two editions began—that is, stressing that notwithstanding our absolute need to breathe untainted air nothing is more important to us than the quality of the water we drink, although, of course, we need clean water for other uses as well. Written with the practitioner, student, novice, or sophisticated consumer in mind, this new edition of *The Drinking Water Handbook* has been thoroughly revised and updated and includes a comprehensive discussion of the Flint, Michigan, lead contamination event, pharmaceuticals and personal care products (PCPPs), and endocrine disruptors.

With regard to our absolute need for air, water, and food, it is important to keep the 5–5–5 Rule in mind: Human beings can survive approximately 5 minutes without breathable air, 5 days without water, and 5 weeks without food. Keep in mind that this rule varies for each individual simply because we are all different and have different requirements. As a whole, however, the 5–5–5 Rule points to our absolute need for the three basic necessities needed to maintain life as we know it.

All of the major cities of the modern world grew up on waterfronts but not because people require such large amounts of water for survival. People typically require no more than 10 pounds of water to create each pound of flesh, but to make a pound of paper requires approximately 250 pounds of water and to produce one pound of fertilizer requires 600 pounds. It is obvious that large cities developed near water primarily because of industry demands for a reliable water supply. In the United States, industry uses over 100 cubic miles of water every year to cool, wash, and circulate its materials, an amount equal to 30% of all the water in the rivers of the world. Of this water we use, very little goes back cleaner than when taken from its source, because as water travels it bears with it the story of where it has been and what it has been used for.

This text recognizes the value of water for use in industry but is not about the industrial use of freshwater; instead, the focus here is on the use of freshwater by humans, who need pure, sweet, clean water to sustain them. This text is about the technology available and required to ensure that the water from our taps is safe. *The Drinking Water Handbook* focuses on keeping our drinking water supplies safe, on current problems with our drinking water supply, and on the technologies available to mitigate the problems. The discussion in this text relating to solutions and technologies is not the result of a "feel good" approach but rather is based on science and technology.

Concern over water quality is not new. Throughout the history of human civilization, concern over the availability of clean drinking water has played an instrumental role in determining where people chose to settle and how these settlements grew into the cities of today. Those of us who reside in the United States are blessed with an abundant freshwater supply. Technology has even allowed us to provide for our arid areas; however, even with that abundance, economic development and population growth are straining the quality and quantity of water available for drinking.

Trillions of gallons of precipitation fall on the United States every day, filling streams, rivers, ponds, lakes, and marshes. That water then percolates through the natural filter that is soil to recharge underground freshwater aquifers. Each day, agricultural irrigators, industrial users, factories, and homeowners withdraw hundreds of billions of gallons from this finite water supply. We use this water for everything from washing dishes and watering the garden to cooling the equipment of industrial complexes. After we are finished with it, the water (a substance always and forever in motion) finds a path back into the water cycle—into a stream, river, pond, lake, marsh, or groundwater supply—along with whatever contaminants it picked up along the way.

When we open our taps to fill our glasses with drinking water, we expect good quality of the water as a basic right. As far as most of us are concerned, what comes from the tap is safe and will cause us no harm. Is this really the case, though? Is the water from our taps really safe? We are hearing now that cancer-causing chemicals exist in virtually every public water supply in the United States.

As water pours forth from the tap into our drinking glasses, another point of concern arises. Has the water been tested in accordance with applicable standards or requirements? Were the tests reliable, or not? Most public health officials claim that our drinking water is safe, but do they really know that for sure? Are federal and state standards for water safety adequate?

This revised and updated edition of *The Drinking Water Handbook* provides technical information regarding what can be found in many tap-water supplies and the measures taken to ensure the health and well-being of consumers. *The Drinking Water Handbook* starts at the source itself, and describes the water purification process through distribution to the tap, to our actual use and reuse of water.

Water, a substance we constantly use and reuse, is recycled via the hydrologic (water) cycle. This text focuses on a particular water cycle, the artificial water cycle that we have created, control, and are utterly dependent on. Called the *urban water cycle*, it consists of the water supply, water purification, water use, and water disposal for reuse common in major metropolitan areas—a manmade cycle that mimics the natural water cycle.

As water users directly affected by the quality of our water, we must take the necessary steps to protect our health by making sure that the water available for drinking is safe—a task not easy to accomplish. We cannot tell the quality of our water just by looking at it; we know that water can look clear in the glass and still contain toxic chemicals or bacterial and viral pathogens that can make users sick.

To purify water, communities rely on municipal treatment plants and a variety of technologies ranging from simple screens, sand filtration, and disinfection to complex chemical and mechanical processes. These systems are not fail safe, though. When they do fail (more often than you might think), water users are left vulnerable to a wide variety of biological and chemical hazards, whether they know it or not.

In 1993, a microscopic organism called *Cryptosporidium* caused more than 400,000 illnesses in Milwaukee, Wisconsin, and left 100 people dead. In 1994, two more outbreaks of the same protozoa killed 19 and sickened more than 100 in Las Vegas, Nevada. Panic over *Cryptosporidium* and *Giardia* caused a 2-month-long boil-alert crisis in Sydney, Australia, between July and September of 1998, one that ended up costing millions of dollars, although no illnesses resulted. That treatment facility paid enormous penalties for incompetent testing—and for not following the maxim, "Better safe than sorry."

Many water users and technologists are no longer ignorant of the current drinking water crisis; the publicity generated by the events in Milwaukee, Las Vegas, and Sydney took care of that. The reappearance of *Cryptosporidium* had an immediate effect. Microbiological parameters and controls returned to the forefront, after having been demoted in the 1970s; disinfection, along with more sophisticated water treatment, came back into favor. Overnight, *Cryptosporidium* and *Giardia* became urgent targets of concern, and the fear of carcinogens (e.g., radon, lead, arsenic) was no longer at the top of the regulatory agenda. In late 1998, concerns about *Cryptosporidium* and *Giardia* were joined by not necessarily a new concern but a concern with new emphasis: disinfection byproducts, including halogenated chloroorganic compounds such as trihalomethanes (THMs). A partial result of these concerns has been the emergence of a new bottled-water industry, one growing at tremendous speed. Consumers want assurance that their water is safe, no matter what, and the current perception is that bottled water is safer than tap water.

Another problem, although not a new one, is pharmaceuticals and personal care products (PPCPs) as pollutants. These pollutants are derived from products used by individuals for personal health or cosmetic reasons or used by agribusiness to enhance the growth or health of livestock. Comprising a diverse collection of thousands of chemicals substances, PPCPs include prescription and over-the-counter therapeutic drugs, veterinary drugs, fragrances, and cosmetics. PPCPs have been present in water and the environment for as long as humans have been using them. The problem with PPCPs in our water supplies is that we do not know what we do not know about their possible impact on human health and the environment. Recent advances in technology, however, have improved our ability to detect and quantify these chemicals, so we can now begin to identify what effects, if any, these chemicals have on human and environmental health. We discuss each of these pressing concerns in this edition of the text.

In the not too distant past, determining whether a surface water source for drinking water was contaminated was accomplished by placing a healthy fish into a stream. If the fish died, the source was contaminated and therefore had to be purified. The degree of contamination was calculated by dividing 100 by the survival time in minutes. Our testing is by far more complex today, but sometimes not much more reliable.

Although primarily designed as an information source and presented in simple, straightforward, easy-to-understand plain English, *The Drinking Water Handbook* also provides a level-headed account, based on years of extensive research, of drinking water quality. *The Drinking Water Handbook* is suitable for use by both the technical practitioner in the field and by students in the classroom. Here is all the information you need to make technical or personal decisions about drinking water.

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